Energy-Related Carbon Dioxide Emissions

In the coming decades, responses to environmental issues could affect patterns of energy use around the world. Actions to limit greenhouse gas emissions could alter the level and composition of energy-related carbon dioxide emissions by energy source.

Carbon dioxide is one of the most prevalent greenhouse gases in the atmosphere. Anthropogenic (human-caused) emissions of carbon dioxide result primarily from the combustion of fossil fuels for energy, and as a result world energy use has emerged at the center of the climate change debate. In the *International Energy Outlook 2005* (*IEO2005*) reference case, world carbon dioxide emissions are projected to rise from 24,409 million metric tons in 2002 to 33,284 million metric tons in 2015 and 38,790 million metric tons in 2025 (Figure 67).[15]

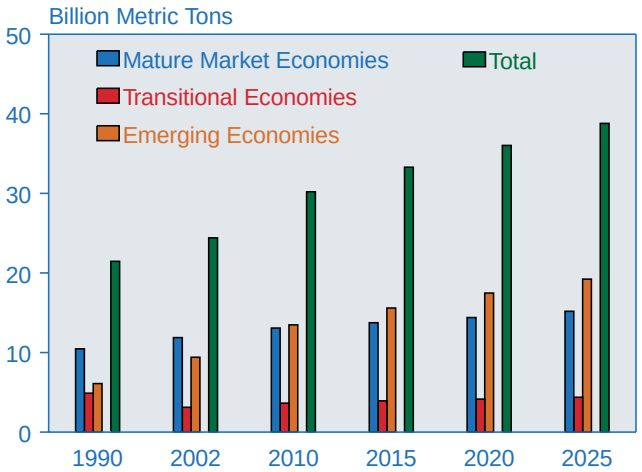
The Kyoto Protocol, which requires participating "Annex I" countries to reduce their greenhouse gas emissions collectively to an annual average of about 5 percent below their 1990 level over the 2008-2012 period, became a legally binding treaty on February 16, 2005, 90 days after it was ratified by Russia. Russia's ratification brought the total number of signatories to more than 55 countries, including Annex I signatories that accounted for more than 55 percent of Annex I carbon dioxide emissions in 1990. The Annex I countries include the 24 original members of the Organization for Economic Cooperation and Development (including the United States), the European Union, and 14 countries with economies in transition (Russia, Ukraine, Estonia, Latvia, Lithuania, and Eastern Europe).[16]

The *IEO2005* reference case projections are based on U.S. and foreign government laws in effect on March 1, 2005. The potential impacts of pending or proposed legislation, regulations, and standards are not reflected in the projections, nor are the impacts of legislation for which implementing mechanisms have not been announced. The *IEO2005* reference case forecast does not include the potential impacts of the Kyoto Protocol, because the treaty does not indicate the methods by which ratifying parties will implement their obligations. Moreover, the Protocol does not address signatory obligations beyond 2012, making it impossible to assess its impacts on energy markets and carbon dioxide emissions through 2025 in the context of a reference case projection.

Another difficulty in projecting energy-related carbon dioxide emissions in the context of the Kyoto Protocol is that, in the 5-year increments of the System for the Analysis of Global Energy Markets (SAGE) model, upon which this forecast is based, 2010 is the only projection year that is part of the Protocol's first commitment period. Further, the specific energy-consuming sectors that will be affected in each country and region have not been identified.

Despite the challenges, it is important to address the possible impacts of the Kyoto Protocol, because they could strongly influence future energy trends. Accordingly, this chapter begins with a presentation of the *IEO2005* reference case forecast for regional carbon dioxide emissions, which can serve as an estimate against which future emissions reductions can be measured. The *IEO2005* Kyoto Protocol case assumes that the emissions goals of the Protocol will be met by the countries that have ratified the treaty and have obligations to limit or reduce their greenhouse gas emissions, using a combination of domestic actions and purchases of international emissions permits. Results from the Kyoto

Figure 67. World Carbon Dioxide Emissions by Region, 1990-2025



Sources: **1990 and 2002:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219 (2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

[15]In keeping with current international practice, *IEO2005* presents data on greenhouse gas emissions in million metric tons carbon dioxide equivalent. The figures can be converted to carbon equivalent units by multiplying by 12/44.

[16]As of May 27, 2005, 149 countries and the European Community had ratified, accepted, acceded to, or approved the Kyoto Protocol. A list of the 149 countries is provided in Appendix J.

Protocol case are analyzed in the second part of the chapter.

Reference Case

Carbon Dioxide Emissions

In the *IEO2005* reference case, world carbon dioxide emissions from the consumption of fossil fuels are expected to grow at an average rate of 2.0 percent per year from 2002 to 2025. Emissions in 2025 are projected to total 38,790 million metric tons, exceeding 1990 levels by 81 percent. Combustion of petroleum products contributes 5,454 million metric tons to the projected increase from 2002, coal 5,353 million metric tons, and natural gas 3,540 million metric tons (Figure 68). Although coal use is projected to grow at a slower rate than natural gas use over the projection period, coal is a more carbon-intensive fuel than natural gas. As a result, the increment in carbon dioxide emissions from coal combustion is larger than the increment in emissions from natural gas.

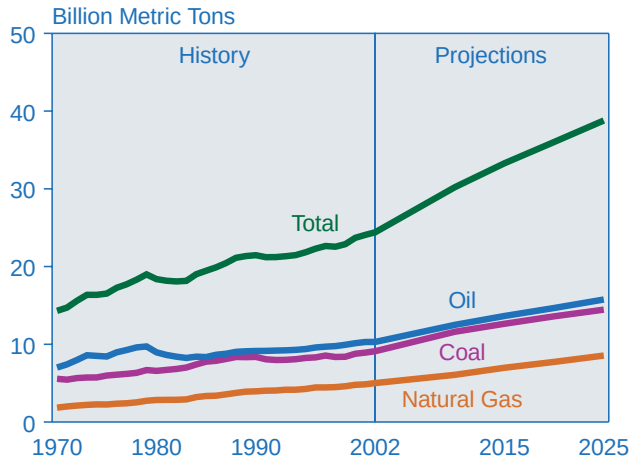
The mature market economies, for the most part, are growing more slowly than the emerging economies, and their growth tends to be in less energy-intensive sectors. As a result, carbon dioxide emissions from the mature market economies are projected to grow by 1.1 percent per year from 2002 to 2025, absent binding constraints (Figure 69 and Table 10). Emissions from North America are projected to grow the most rapidly among the mature market regions, by 1.5 percent per year. North America's average annual increase in gross domestic product (GDP) is 3.1 percent over the forecast horizon, and that strong economic growth, combined with projected increases in population, drives the demand for fossil fuels and thus the projected increase in carbon dioxide emissions.

In contrast to North America, Western Europe and mature market Asia are projected to have fairly modest growth in GDP (2.0 and 1.8 percent per year, respectively) and either flat or declining population numbers over the forecast. Thus, only limited growth in demand for energy is projected for those regions, leading to slower growth in emissions. For Western Europe, carbon dioxide emissions are projected to grow by 0.5 percent per year on average from 2002 to 2025, and for mature market Asia the projected average annual increase in emissions is 0.6 percent.

The economic collapse of the transitional economies of Eastern Europe and the former Soviet Union (EE/FSU) dampened the growth of carbon dioxide emissions worldwide between 1990 and 2002. In the *IEO2005* reference case, carbon dioxide emissions in the EE/FSU region are projected to increase on average by 1.5 percent per year, to 3,937 million metric tons in 2015 and 4,386 million metric tons in 2025 (Figure 70). The transitional economies are dominated by Russia, the region's largest economy, which accounts for 51 percent of its energy consumption and 45 percent of related carbon dioxide emissions.

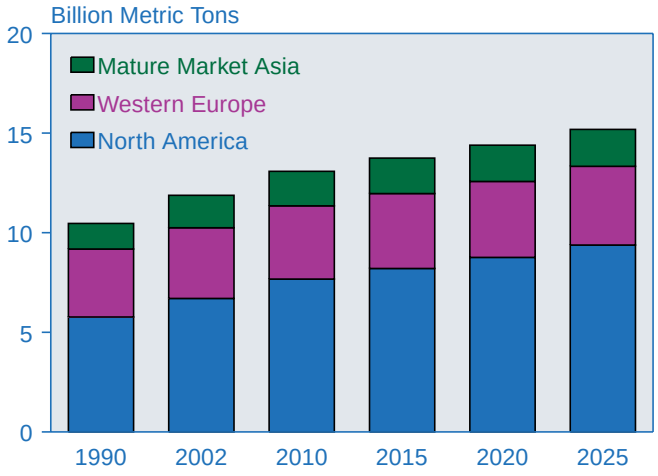
Although GDP growth in the EE/FSU region is projected to average 4.4 percent per year from 2002 to 2025, improvements in energy infrastructure are expected to keep the growth in energy demand at an annual average of 1.6 percent. In addition, an increase in natural gas as a share of total energy production and a drop in coal's

Figure 68. World Carbon Dioxide Emissions by Fuel Type, 1970-2025



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219(2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

Figure 69. Carbon Dioxide Emissions in the Mature Market Economies, 1990-2025



Sources: **1990 and 2002:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219 (2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

share are expected to lower the carbon intensity of energy supply in the region and keep carbon dioxide emissions in the transitional economies well below their 1990 level of 4,894 million metric tons.

For the world's emerging economies, the reference case projects strong economic growth driven largely by the energy-intensive industrial and transportation sectors. Accordingly, carbon dioxide emissions in the emerging economies are projected to grow at twice the rate projected for the transitional economies and almost three times the rate for the mature market economies, averaging 3.2 percent per year from 2002 to 2025. The most rapid increases in carbon dioxide emissions are projected for the nations of emerging Asia (Figure 71).

Carbon Dioxide Intensity

World carbon dioxide intensity has improved (decreased) substantially over the past three decades, falling from 853 metric tons per million 2000 U.S. dollars of GDP in 1970 to 517 metric tons per million dollars in 2002. Although the pace of improvement in emissions intensity is expected to be slower over the 2002 to 2025 period than over the past three decades, a continuing decline in intensity is projected in the reference case, to 422 metric tons per million dollars in 2015 and 344 metric tons per million dollars in 2025.

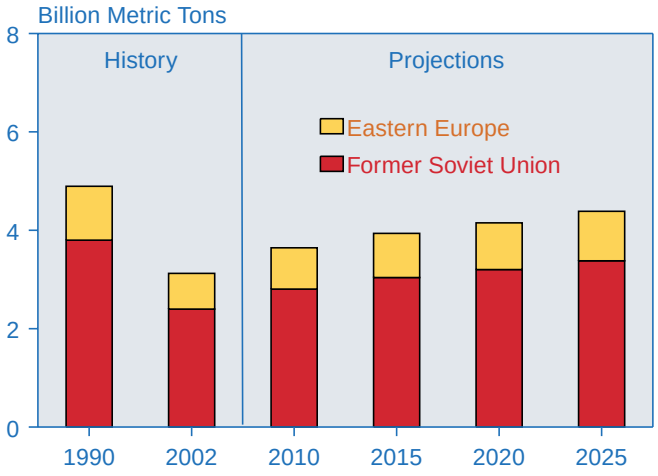
On a regional basis, the most rapid rates of improvement in carbon dioxide intensity are projected for the transitional economies of the EE/FSU and for the emerging

Table 10. World Carbon Dioxide Emissions by Region, 1990-2025
(Million Metric Tons)

Region	History		Projections				Average Annual Percent Change	
	1990	2002	2010	2015	2020	2025	1990-2002	2002-2025
Mature Market Economies	**10,465**	**11,877**	**13,080**	**13,745**	**14,392**	**15,183**	**1.1**	**1.1**
North America	5,769	6,701	7,674	8,204	8,759	9,379	1.3	1.5
Western Europe	3,413	3,549	3,674	3,761	3,812	3,952	0.3	0.5
Mature Market Asia	1,284	1,627	1,731	1,780	1,822	1,852	2.0	0.6
Transitional Economies	**4,894**	**3,124**	**3,643**	**3,937**	**4,151**	**4,386**	**-3.7**	**1.5**
Emerging Economies	**6,101**	**9,408**	**13,478**	**15,602**	**17,480**	**19,222**	**3.7**	**3.2**
Asia	3,890	6,205	9,306	10,863	12,263	13,540	4.0	3.5
Middle East	845	1,361	1,761	1,975	2,163	2,352	4.1	2.4
Africa	655	854	1,122	1,283	1,415	1,524	2.2	2.5
Central and South America	711	988	1,289	1,480	1,639	1,806	2.8	2.7
Total World	**21,460**	**24,409**	**30,201**	**33,284**	**36,023**	**38,790**	**1.1**	**2.0**

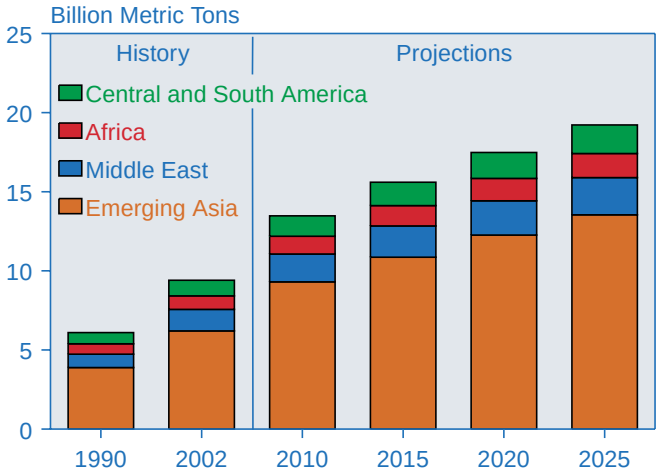
Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219(2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

Figure 70. Carbon Dioxide Emissions in the Transitional Economies, 1990-2025



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219 (2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

Figure 71. Carbon Dioxide Emissions in the Emerging Economies, 1990-2025



Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219 (2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

economies of China and India. In the FSU, economic recovery from the upheaval of the 1990s is expected to continue throughout the forecast. The FSU nations are also expected to replace old, inefficient capital stock as economic recovery progresses.

The Eastern European nations began their economic recovery much earlier than the nations of the FSU. As a result of strong investment in improving the efficiency of energy use among Eastern European countries and a push to increase the use of natural gas, carbon dioxide intensity fell by more than 43 percent in Eastern Europe between 1990 and 2002, as compared with an increase of almost 4 percent in Russia and a decrease of 27 percent in the other FSU nations. Improvement in carbon dioxide intensity in Eastern Europe is projected to continue over the projection period, at an average rate of 2.6 percent per year (Table 11).

Emerging Asia is expected to see fairly rapid improvement in carbon dioxide intensity over the 2002-2025 period, primarily as a result of rapid economic growth rather than a switch to less carbon-intensive fuels. China and India, in particular, are expected to remain heavily reliant on fossil fuels, especially coal, in the *IEO2005* reference case, but their combined annual GDP growth is projected to average 5.9 percent, compared with an expected 3.9-percent annual rate of increase in fossil fuel use over the projection period. China's carbon dioxide intensity is expected to decrease by 2.1 percent per year on average between 2002 and 2025 and India's by 2.4 percent per year.

Rates of improvement in carbon dioxide intensity could vary considerably in the future, based on technological advances, government policy initiatives, and economic growth rates. In the *IEO2005* reference case, world carbon dioxide intensity is projected to fall from 517 metric tons per million 2000 dollars of GDP in 2002 to 344 metric tons per million dollars in 2025; however, if world economic growth expands to the levels projected in the *IEO2005* high economic growth case, carbon dioxide intensity could fall more quickly, to 325 metric tons per million dollars in 2025. In contrast, if the world economy expands more slowly, as in the low economic growth case, carbon dioxide intensity could decline to a projected 383 metric tons per million dollars in 2025.

Table 11. Carbon Dioxide Intensity by Region and Country, 1970-2025
(Metric Tons per Million 2000 U.S. Dollars of Gross Domestic Product)

Region	History				Projections				Average Annual Percent Change	
	1970	1980	1990	2002	2010	2015	2020	2025	1990-2002	2002-2025
Mature Market Economies										
North America										
United States	1,117	917	701	571	501	459	423	393	-2.1	-1.6
Canada	1,046	883	691	612	562	527	495	481	-1.7	-1.0
Mexico	351	405	452	377	340	317	286	255	0.2	-1.7
Western Europe	695	624	471	377	333	307	281	264	-1.9	-1.5
Mature Market Asia										
Japan	627	497	348	359	310	291	274	259	-1.7	-1.4
Australia/New Zealand	1,094	715	702	721	667	621	583	544	-1.3	-1.2
Transitional Economies										
Russia	837	897	820	850	635	568	504	445	0.0	-2.8
Other FSU	1,211	1,210	1,843	1,346	926	801	682	602	0.3	-3.4
Eastern Europe	1,454	1,445	1,198	679	549	482	422	372	-2.3	-2.6
Emerging Economies										
Asia	890	766	637	470	434	389	343	300	-2.0	-1.9
China	2,560	1,943	1,252	605	570	500	436	375	-4.4	-2.1
India	286	312	346	324	272	242	212	185	0.4	-2.4
South Korea	791	868	698	680	555	515	484	454	-0.5	-1.7
Middle East	506	566	894	951	833	761	687	621	2.0	-1.8
Africa	522	542	609	595	549	518	477	431	0.4	-1.4
Central and South America	481	409	408	414	407	383	347	314	-0.5	-1.2
Total World	**853**	**753**	**649**	**517**	**461**	**422**	**381**	**344**	**-1.6**	**-1.8**

Sources: **History:** Energy Information Administration (EIA), *International Energy Annual 2002*, DOE/EIA-0219(2002) (Washington, DC, March 2004), web site www.eia.doe.gov/iea/. **Projections:** EIA, System for the Analysis of Global Energy Markets (2005).

Kyoto Protocol Case

Modeling Approach

Under the Kyoto Protocol, participating Annex I nations are required to reduce or limit emissions of carbon dioxide and other greenhouse gases over the first commitment period (January 2008 to December 2012) to a level that was determined as part of the negotiation process. The year 1990 was used as the base year for most countries, although some were allowed to use other years.[17] To fulfill their obligations under the treaty, the Annex I countries must limit their emissions over the 5-year commitment period to an annual average that is at or below their commitment goals. Because the SAGE model used to generate *IEO2005* forecasts projects in 5-year increments, 2010 is used as the basis year for achieving commitments in the first period.[18]

The SAGE model comprises 15 regions. In the Kyoto Protocol case, the model regions affected by the treaty are Canada, Japan, Western Europe, Eastern Europe, and the FSU. Although New Zealand has ratified the Protocol and intends to honor the terms of the treaty, Australia has not. In SAGE, New Zealand and Australia are treated as a single entity; and Australia's energy use far exceeds New Zealand's. Therefore, projections for Australia/New Zealand are not included in the results of the Kyoto Protocol case.

In the formulation of the Kyoto Protocol case, assumptions were made about how the affected regions would achieve their reductions, based whenever possible on official government statements. For instance, the European Union (EU) has stated that "most" of its greenhouse gas emissions reductions must be achieved domestically. The Kyoto Protocol case therefore assumes that 50 percent of the aggregate emission reduction for Western Europe will be met by domestic reductions, as opposed to using the international market mechanisms allowed under the Protocol (see box on page 83).

Both Japan and Canada have higher domestic reduction costs than Western Europe, and neither country has announced its intentions on the specific share of reductions that must be reached through domestic actions. In the Kyoto Protocol case, both countries are assumed to achieve 25 percent of their total reductions domestically.

In the *IEO2005* Kyoto Protocol case, a country or region is first required to achieve its domestic reduction goal. After the domestic requirement has been met, the country or region is free to seek other means of meeting its overall reduction goal—for example, by trading carbon permits internationally. In SAGE, the "shadow price" of reducing carbon dioxide emissions by 1 metric ton in a given country or region is used to determine the price that the country or region would be willing to pay for the next additional reduction of 1 metric ton. If the price of a carbon permit traded internationally exceeds the shadow price of the domestic reduction, then the country or region would be better off achieving that reduction domestically. If the price of a purchased permit is less than the shadow price, then the country or region would be expected to choose the trading option.

Unlike the mature market economies that have ratified the Kyoto Protocol, the EE/FSU transitional economies have reported estimated emissions that are below their Kyoto goal levels. Over the forecast period the credits they provide would be enough to satisfy all the other Annex I countries' demand for reductions once their domestic goals are met. The credits available from the EE/FSU countries have no direct costs, because they do not require any actions to be taken. Under the model structure of perfect competition, price equals cost; however, a transaction cost of $10 per ton was imposed in the SAGE model in order to derive a price greater than zero.

Summary

The Kyoto Protocol case assumes that energy use will not vary from the reference case forecast for Annex I countries that are not expected to participate in the treaty (the United States and Australia, for example) or for countries that are not required to make reductions according to the terms of the treaty (China and India, for example). As a result, only the projections for energy use in the Annex I nations committed to participating in the Kyoto Protocol are changed in the Kyoto Protocol case. For the participating Annex I group, total energy demand in the Kyoto Protocol case is projected to be 3 quadrillion Btu lower than in the reference case in 2010, and almost 4 quadrillion Btu lower in 2025, assuming that the Kyoto targets remain constant over the entire forecast period (Table 12).

In the Kyoto Protocol case, energy-related carbon dioxide emissions in the participating nations are projected to be 402 million metric tons lower than in the reference case in 2010 and 593 million metric tons lower in 2025. Total coal use among the participating Annex I nations in 2025 is projected to be about 18 percent lower than in the reference case in 2025, and the carbon dioxide emissions associated with their coal use are projected to be nearly 21 percent lower than in the reference case, primarily because of the expected penetration of carbon sequestration technologies in Western Europe. These technologies sequester 90 percent of the emissions from coal-fired generation. The penetration of the sequestration technology also limits the potential for renewables development.

[17]The countries using a base year other than 1990 are Bulgaria (1988), Hungary (1985-87), Poland (1988), and Romania (1989).
[18]For detailed assumptions in the Kyoto Protocol case, see Appendix G.

Total oil consumption for the participating nations is almost 2 quadrillion Btu lower in the Kyoto Protocol case in 2025, and the emissions associated with their oil use are 143 million metric tons lower. In the short term, natural gas is expected to displace coal use among the participating Annex I nations, because natural gas is cleaner than coal and has an economic advantage over nuclear and renewable energy sources that produce no net carbon dioxide emissions. In the longer term, as the marginal costs of carbon dioxide reductions increase, natural gas becomes less attractive than the non-fossil fuels, especially nuclear power, which is projected to begin to displace natural gas by 2025. The projection for natural gas consumption in the Kyoto Protocol case is 2.8 quadrillion Btu higher than the reference case projection in 2010 and 1.7 quadrillion Btu in 2025, when non-fossil fuel use is projected to be 1.4 quadrillion Btu higher in the Kyoto Protocol case than in the reference case.

The projected penetration of renewable fuels in the energy markets of participating Annex I countries is lower in the Kyoto Protocol case than in the reference case, for a number of reasons. Electricity generation from nuclear power is 1.9 percent higher in the Kyoto Protocol case than in the reference case in 2010 and 12.5 percent higher in 2025; and total energy use is 1.8 percent lower in 2010 and 1.7 percent lower in 2025. As a result, even though generation from non-fossil fuels makes up a larger share of total energy consumption in the Kyoto Protocol case than in the reference case, renewable generation is lower.

Regional Projections

Canada

Canada is the only Annex I country in North America that has ratified the Kyoto Protocol. Its goal is to reduce carbon dioxide emissions to 6 percent below 1990 levels, to a total of about 444 million metric tons in 2010, or 35 percent below the *IEO2005* reference case projection of 681 million metric tons. As indicated above, it is assumed that 59.3 million metric tons (25 percent) of the carbon dioxide emission reductions in Canada will be met through domestic actions, and 177.8 million metric tons (75 percent) will be met through the Protocol's market mechanisms.

In April 2005, Canada unveiled its plan for compliance, based on multiple approaches. The plan includes binding constraints on the country's electric power sector and large-scale industrial emitters, subsidies for wind power, a "partnership fund" between government and industry, soil management goals, and programs in consumer awareness and voluntary reductions by automakers. The Canadian government also has budgeted $3.2 billion to $4.0 billion for purchases of carbon credits, depending on the permit price [***1***].

The Kyoto Protocol case projects that, at the 25-percent domestic level, the marginal cost for emission reductions from domestic sources in Canada will be around $26 per metric ton of carbon dioxide in 2010 and, assuming that constraints are held constant after 2012, about $36 per metric ton in 2025. Canada's energy demand in 2010 is projected to be 0.3 quadrillion Btu (1.8 percent) lower in the Kyoto Protocol case than in the *IEO2005* reference case, and its energy-related carbon dioxide emissions in 2010 are projected to be 59 million metric tons (8.7 percent) lower (Table 13). In 2025, its projected energy demand is 0.5 quadrillion Btu below the reference case level (assuming that the Kyoto goals for Canada will not change over the forecast period), and its energy-related carbon dioxide emissions are 91 million metric tons lower than in the reference case.

Canada's coal consumption and associated carbon dioxide emissions are projected to be about 41 percent lower in 2010 and 55 percent lower in 2025 in the Kyoto Protocol case than in the reference case. Emissions associated with oil consumption are projected to be about the same in the two cases in 2025, and emissions from natural gas use are projected to be 5.2 percent higher in 2010 and 11.6 percent higher in 2025. Canada's consumption of non-fossil energy in 2025 is projected to be 0.9 percent

Table 12. Energy Consumption and Carbon Dioxide Emissions by Fuel in Participating Annex I Countries in Two Cases, 2010 and 2025

	Energy Consumption (Quadrillion Btu)				Carbon Dioxide Emissions (Million Metric Tons)			
	2010		2025		2010		2025	
Fuel	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case
Oil	58.1	56.8	63.2	61.4	3,803	3,719	4,142	3,998
Natural Gas	54.9	57.6	71.3	73.1	2,896	3,046	3,765	3,863
Coal	27.0	22.1	26.7	21.9	2,504	2,036	2,472	1,943
Nuclear	17.3	17.7	18.3	20.6	—	—	—	—
Renewables	14.4	14.4	17.8	16.9	—	—	—	—
Total	**171.7**	**168.6**	**197.3**	**193.8**	**9,203**	**8,801**	**10,386**	**9,793**

Source: Energy Information Administration, System for the Analysis of Global Energy Markets (2005).

higher in the Kyoto Protocol case than in the reference case.

Western Europe

The countries of Western Europe have ratified the Kyoto Protocol individually, and the EU has adopted a goal of reducing its member countries' aggregate carbon dioxide emissions to 8 percent below their 1990 level, or to an average of 3,123 million metric tons per year during the first commitment period. That goal, which is about 15 percent below the 2010 projection in the *IEO2005* reference case, would require a reduction of 545 million metric tons from the reference case level, 50 percent of which (273 million metric tons) is assumed to be met through domestic programs.

The EU has developed its own plan for emissions trading in the 2005 to 2007 period, in preparation for the first Kyoto commitment period in 2008. The EU Greenhouse Gas Emission Trading Scheme (EU ETS) allocates emissions to more than 12,000 specific installations across 25 member countries and requires reductions or permits to meet those allocated goals; however, there have been some mixed messages coming out of the EU in the

Market Mechanisms Under the Kyoto Protocol

In order to help participating countries meet their goals, the Kyoto Protocol includes market mechanisms that are designed to allow some flexibility in reaching reduction targets. The three primary market mechanisms are described below.

Clean Development Mechanism (CDM): The CDM is designed to promote participation by emerging economies in projects that lead to certified and verifiable emissions reductions. It allows Annex I countries to invest in emissions reduction projects in non-Annex I countries and apply credits received for those projects toward meeting their commitment goals. Currently, CDM reductions achieved between 2000 and 2012 may be used to meet requirements in the first commitment period, 2008 to 2012.

Several recent studies have estimated that the average annual demand for CDM Certified Emissions Reductions (CERs) will be between 50 and 500 million metric tons, and that the cost of a CER will be between $5 and $15 per metric ton.[a] Emission reductions in 2010 of 400 million metric tons carbon dioxide equivalent would require annual investments of $10 billion. For reference, annual foreign direct investment in emerging economies between 1997 and 2002 averaged $140 billion,[b] and it is estimated that the emerging economies will need a total of $192 billion annually in energy investments between 2001 and 2010.

Finally, CDM projects generally require a leadtime of 4 to 5 years to begin receiving credits. Because of risks to both the buyers and sellers of CERs derived from CDM projects and the abundance of excess emissions credits—so-called "hot air"—that could be sold internationally over the forecast period, the *IEO2005* Kyoto Protocol case does not explicitly include CDM projects. However, CDM projects serve as a mitigating factor to prevent the countries in possession of hot air credits from exercising monopoly power, since in many cases CDM projects would offer the best alternative to emissions trading after participating countries have met their domestic goals.

Emissions Trading: This market mechanism allows emitters who are in an advantageous position with regard to emissions reductions (as most of the EE/FSU countries currently are) to make further reductions below their target levels and sell the difference to emitters whose domestic reduction costs are relatively high. In theory, such trading would allow the necessary emission reduction to be achieved in the aggregate at the lowest possible cost, regardless of where they take place. Indeed, Russia and Ukraine could in theory meet all the required reductions of Annex B countries.[c] After domestic emissions reduction goals are achieved, the *IEO2005* Kyoto Protocol case assumes that additional reductions will be achieved by emissions trading.

Joint Implementation (JI): This market mechanism is similar to the CDM, except that JI projects would involve only the Annex B countries, and only reductions achieved during the 2008-2012 commitment period may be used. Because the SAGE model aggregates all the Western European countries into one region, JI is implicit in the projections for Western Europe. In contrast, because Canada and Japan are represented as single regions in SAGE, each must achieve its domestic goals (in the modeling process) independently of JI projects. As with CDM projects, the *IEO2005* Kyoto Protocol case assumes that emissions trading will be the least-cost alternative to reductions once domestic goals are achieved.

[a]E. Haites, *Estimating the Market Potential for the Clean Development Mechanism: Review of Models and Lessons Learned*. Prepared for the World Bank Carbon Finance Business PCF*plus* Research Program, the International Energy Agency, and the International Emissions Trading Association (Washington DC: PCF*plus* Report 19, June 2004), p. v, web site www.iea.org/textbase/papers/2004/cdm.pdf.
[b]E. Haites, *Estimating the Market Potential for the Clean Development Mechanism: Review of Models and Lessons Learned*, p. iv.
[c]Annex B countries are the mature market economies that are part of Annex I, excluding the transitional economies.

months since the EU ETS was implemented. Earlier indications were that the EU wanted to meet its Kyoto goals with a "significant element of their [reduction] efforts" coming from domestic cuts [2], but recent analysis has indicated that the cost of achieving domestic reductions in countries such as the United Kingdom may have been underestimated [3].

The *IEO2005* Kyoto Protocol case assumes that 50 percent of the emission reductions in Western Europe will be based on domestic actions, and the cost projections are highly sensitive to that assumption. At the 50-percent domestic reduction level, the cost of reducing carbon dioxide emissions in the region is projected to be $48 per metric ton in 2010, rising to $64 per metric ton in 2025. Western Europe's total projected energy demand is 2.2 quadrillion Btu lower in the Kyoto Protocol case than in the reference case in 2010 and 2.8 quadrillion Btu lower in 2025 (Table 14). Energy-related carbon dioxide emissions are projected to be 273 million metric tons lower than in the reference case in 2010 and 415 million metric tons lower in 2025.

Western Europe's coal consumption is projected to be 46 percent lower in 2010 in the Kyoto Protocol case than in the reference case, and the carbon dioxide emissions associated with its coal use are projected to be 45 percent lower. In 2025, however, when coal use in Western Europe is projected to be 47 percent lower than in the reference case, coal-related emissions are projected to be 58 percent lower, because technologies become available in Western Europe by 2025 that will allow 90 percent of the carbon dioxide emissions associated with coal combustion to be captured and sequestered. Oil consumption and related emissions are projected to be about 5 percent lower in the Kyoto Protocol case in 2025; natural gas consumption and associated emissions are projected to be almost 7 percent higher in 2025; and consumption of non-fossil fuels is projected to be 2.4 percent higher than in the reference case in 2025.

Japan

Japan's goal for reducing carbon dioxide emissions under the Kyoto Protocol is estimated at 930 million metric tons, or 6 percent below its 1990 emissions level. That target represents a reduction of about 280 million metric tons or 23 percent from the *IEO2005* reference case projection for 2010. If 25 percent of the goal is to be met domestically, energy-related carbon dioxide emissions will have to be cut by 70.1 million metric tons from the reference case projection in 2010, with the remaining

Table 13. Energy Consumption and Carbon Dioxide Emissions by Fuel in Canada in Two Cases, 2010 and 2025

	Energy Consumption (Quadrillion Btu)				Carbon Dioxide Emissions (Million Metric Tons)			
	2010		2025		2010		2025	
Fuel	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case
Oil	4.9	4.9	5.5	5.5	306	305	344	341
Natural Gas	4.0	4.2	4.8	5.4	210	220	253	282
Coal	1.8	1.1	2.3	1.0	166	97	210	93
Nuclear	1.2	1.2	1.2	1.2	—	—	—	—
Renewables	3.8	3.9	5.1	5.1	—	—	—	—
Total	**15.6**	**15.3**	**18.8**	**18.3**	**681**	**622**	**807**	**716**

Source: Energy Information Administration, System for the Analysis of Global Energy Markets (2005).

Table 14. Energy Consumption and Carbon Dioxide Emissions by Fuel in Western Europe in Two Cases, 2010 and 2025

	Energy Consumption (Quadrillion Btu)				Carbon Dioxide Emissions (Million Metric Tons)			
	2010		2025		2010		2025	
Fuel	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case
Oil	29.2	28.3	31.0	29.5	1,951	1,901	2,074	1,967
Natural Gas	17.7	20.1	22.9	24.5	934	1,066	1,210	1,290
Coal	8.2	4.5	6.9	3.6	783	428	661	281
Nuclear	9.0	9.3	7.8	9.0	—	—	—	—
Renewables	6.1	5.9	7.4	6.6	—	—	—	—
Total	**70.2**	**68.0**	**76.1**	**73.3**	**3,668**	**3,395**	**3,952**	**3,537**

Source: Energy Information Administration, System for the Analysis of Global Energy Markets (2005).

reduction of 210.4 million metric tons accomplished through purchases of emissions permits. In the *IEO2005* Kyoto Protocol case, Japan's domestic effort is projected to yield marginal costs of $49 per metric ton of carbon dioxide in 2010 and $43 per metric ton in 2025.

Japan's energy demand in 2010 is projected to be 0.8 quadrillion Btu lower in the Kyoto Protocol case than in the reference case (Table 15). Assuming that the country's goals for the first commitment period remain in place at the same level through 2025, its total energy demand in 2025 is projected to be 0.5 quadrillion Btu lower than in the reference case, and its energy-related carbon dioxide emissions are projected to be 70 million metric tons lower than the reference case projection in 2010 and 78 million metric tons lower in 2025.

Japan's coal consumption is projected to be 7.5 percent lower in 2025 in the Kyoto Protocol case than in the reference case, with a smaller reduction (3.6 percent) projected for oil consumption relative to the reference case projection in 2025. Because natural gas is expected to be used as a substitute for coal in the short run to help Japan reach its Kyoto goal, emissions associated with natural gas consumption are projected to be 4.1 percent higher in the Kyoto Protocol case than in the reference case in 2010.

In March 2005, a proposed fossil fuel tax was stopped by a government panel chaired by Prime Minister Junichiro Koizumi [*4*]. Currently, the Japanese plan calls for voluntary industry efforts as the cornerstone of the plan to meet its goals in the first commitment period. A shrinking population is expected to help Japan meet its goals in later years.

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Table 15. Energy Consumption and Carbon Dioxide Emissions by Fuel in Japan in Two Cases, 2010 and 2025

	Energy Consumption (Quadrillion Btu)				Carbon Dioxide Emissions (Million Metric Tons)			
	2010		2025		2010		2025	
Fuel	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case	Reference Case	Kyoto Protocol Case
Oil	10.9	10.4	11.0	10.6	657	623	662	628
Natural Gas	3.2	3.3	3.9	3.8	167	174	208	198
Coal	4.3	3.8	4.1	3.8	386	343	372	338
Nuclear	3.3	3.3	4.0	4.4	—	—	—	—
Renewables	1.2	1.2	1.7	1.6	—	—	—	—
Total	**22.9**	**22.1**	**24.7**	**24.2**	**1,211**	**1,141**	**1,242**	**1,164**

Source: Energy Information Administration, System for the Analysis of Global Energy Markets (2005).